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Anomalous dehydration of the TTL during January 2013: evidence from balloon, aircraft and satellite observations

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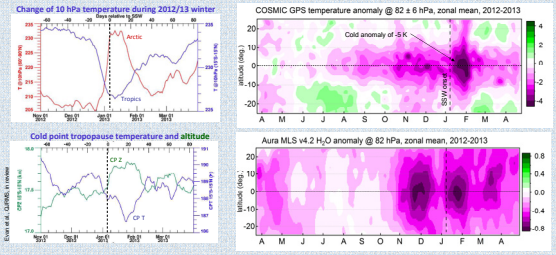
Abstract

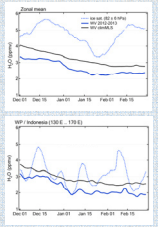
The goal of this study is to comprehensively document an anomalous dehydration of the Tropical Tropopause Layer (TTL) related to a major Sudden Stratospheric Warming (SSW) in January 2013. The analysis involves the data of balloon soundings of water vapour at various tropical locations using FLASH-B, Pico-SDLA and CFH hygrometers as well as NOAA Water instrument flown onboard high-altitude Global Hawk aircraft. Simultaneous water vapour and backscatter measurements by FLASH-B and COBALD sondes provide information on tropopause clouds formation process. Satellite observations of water vapour by Aura MLS are used to derive the deviation from climatological values. Trajectory modeling is applied for locating the dehydration source spots. Spatiotemporal evolution of dehydration at different scales is characterized after combining the consistent in situ and satellite water vapour observations. All data sets provide evidence of rapid and severe dehydration of the TTL throughout the tropical belt shortly after the onset of SSW. In situ measurements around the Cold Point Tropopause (CPT) show up to 2 ppmv of negative deviation from MLS 10-year climatology with extreme water mixing ratios below 1 ppmv in the Western Pacific region.

The TTL dehydration case of 2013 is compared with previous similar occurrences and the role of extra-tropical dynamics in setting the global stratospheric water budget through thermal response in the TTL is pointed out.

Meteorological situation during boreal winter 2012/13

Rapid cooling and lifting of the tropical tropopause linked with Sudden Stratospheric Warming (SSW) on Jan 6, 2013 results in anomalous drying (up to 40% in zonal mean) of the TTL

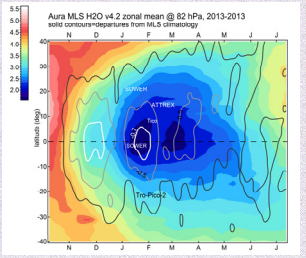




MLS tropical (15 S .. 15 N) water vapour at 82 hPa during Austral summer 2012/2013 (blue), 10 year MLS climatology (black) and saturation mixing ratio (dashed blue) calculated from COSMIC GPS temperature and pressure. Top: zonal mean. Bottom: 130 E, 170 E

Measurement campaigns during January-February 2013

Extensive in situ observations of water vapour all around the tropical belt during the dehydration period



Captions in the plot indicate the approximate latitudinal location and time period of the measurement campaigns

TroPico-2 balloon campaign. Bauru, Brazil (22 S, 49 W):
FLASH-B Lyman-alpha and Pico-SDLA TDL balloon-borne hygrometers

SOWER-2013 balloon campaign.
Biak, Indonesia (1.4 S, 136 E) and Hanoi, Vietnam (21 N, 106 E): CFH sondes.

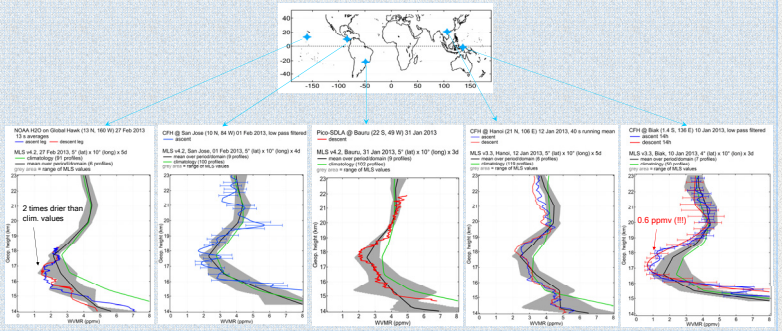
ATTREX aircraft campaign. Tropical Central Pacific.
NOAA H2O instrument onboard Global Hawk UAV.

TicoSonde balloon campaign. San Jose, Costa-Rica (10 N, 84 W). CFH sondes.

Picture titles and credits (left to right):
Launch of 500 m³ balloon carrying Pico-SDLA instrument in Bauru (TroPico)
Launch of 1200 g weather balloon with FLASH-B and COBALD sondes in Bauru (TroPico)
Launch of 800 g weather balloon with CFH sonde in Biak (SOWER)
Global Hawk unmanned aircraft during ATTREX (NASA)

In situ observations of dehydration

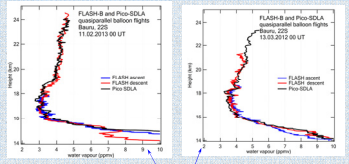
Comparison of selected in situ H2O profiles with the nearest MLS profiles and MLS climatology



- All in situ profiles reveal negative deviation from MLS climatology, reaching ~2 ppmv (~70%)
- Minimum mixing ratio above Western Pacific (0.6 ppmv ±25%, driest ever)

Balloon soundings within TroPico-2 campaign (Brazil, 22 S)

Hygrometers intercomparison

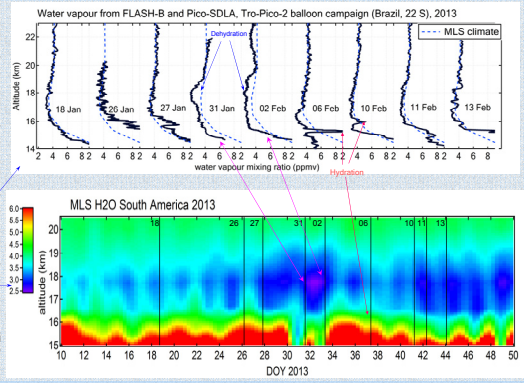


Excellent agreement between FLASH and Pico-SDLA allows combining their profiles into a single WV series

Series of profiles reveal dehydration signatures from 31 Jan through 6 Feb, which are followed by TTL hydration episodes

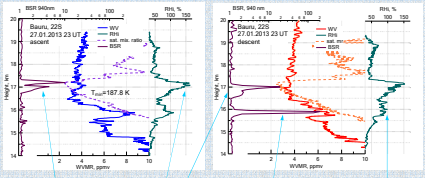
Balloon soundings are representative of the synoptic-scale situation above South America observed by MLS

Combined water vapour profiles from 2 hygrometers



Bottom: Water vapor profiles (FLASH-B and Pico-SDLA) above Bauru and climatological profile from MLS for the given time period. Top: MLS H_2O time series above tropical South America, vertical lines = balloon soundings.

Formation of subvisible cirrus clouds at CPT level with extreme supersaturation



Vertical profiles of water vapour (FLASH-B), backscatter ratio (COBALD), RHice and saturation mixing ratio (PT from Vaisala RS92) obtained during balloon ascent (left) and descent (right).

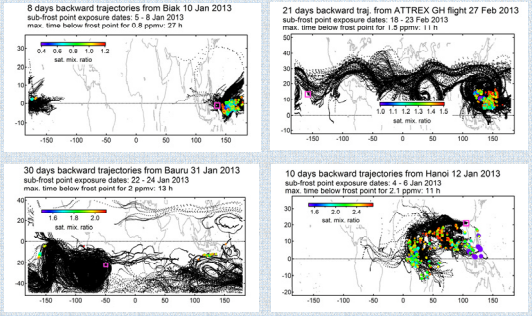
- Ascent and descent through TTL are 30 km / 50 min apart. Thanks to the wind shear the ascent and descent profiles are taken in the same air mass as suggested by trajectory analysis.
- Two types of cirrus clouds with different properties and dehydration potentials (see Jensen et al., 2013): *what saturation threshold should be used for dehydration studies??*

Location of dehydration spots

- In order to find out where the sampled air masses were dehydrated to the observed levels the ensembles of backward trajectories ending at the sounding locations were calculated.
- Hysplit model driven by GDAS meteorological analysis (0.5° x 0.5° horizontal resolution, 55 pressure levels up to 10 hPa, ~ 5 levels in TTL
- Ensembles of 500 trajectories spaced by 0.1° / 100 m steps from a 1° x 1° x 1 km domain centered at the driest level at each sounding location
- Calculation of saturation mixing ratio along each trajectory shows were the sampled air could have been dehydrated

=> Dehydration mostly above WP

Ensembles of backward trajectories (3 h steps) showing the dehydration spots
Colored markers show where the sampled air was cooled below the frost point



Summary

- Major SSW developed on January 6, 2013 resulted in a rapid increase of stratospheric polar temperatures by ~30 K,
  Tropical stratosphere temperatures dropped at the same time;
- As a result of the easterly shear QBO phase and the SSW, the tropical tropopause in January 2013 was anomalously cold (- 5 K anomaly) and elevated (85 hPa);
- Zonal mean CPT temperature and tropical water vapour mixing ratio decreased by ~ 2 K and ~ 0.8 ppmv respectively within the first 15 days of January:
  the water vapor change was likely a result of dehydration associated with the rapid cooling of the tropical CPT during that period
- High-resolution in situ measurements of water vapour at different tropical locations consistently show large negative anomalies compared to MLS climatology , reaching - 2 ppmv (70%);
- A record-low mixing ratio of 0.66 ppmv (±25%) was detected by CFH above Biak in the Western Pacific region, where cooling and drying were largest according to satellite observations by COSMIC and MLS
- Trajectory modeling using Hysplit and GDAS analysis showed that the air sampled by in situ instruments at different locations has been processed by sub-frost point temperatures predominantly above Western Pacific
- Balloon soundings in Brazil within TroPico-2 campaign:
  - Excellent agreement between FLASH and Pico-SDLA allows combining their profiles into a single WV series
  - Temporal evolution of dehydration revealed by the balloon profiles is captured by MLS synoptic-scale averages
  - Simultaneous water and aerosol measurements by FLASH-B and COBALD sondes reveal two types of TTL cirrus clouds with different dehydration potential

References.
Evan, S., Rosenlof, K., Thornberry, T., Rollins, A. and Khaykin, S.: TTL cooling and drying during the January 2013 Stratospheric Sudden Warming, Q.J.R. Meteorol. Soc., in review, 2015.
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